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THE TORNADO: ESPY'S EXPERIMENTS.

THESE investigations of Espy upon what actions may be considered as taking place in the upper air, as has been already said, are of the highest importance, and demand a special consideration. A proper interpretation of his results will help us in all our studies and reasonings. One of the most serious difficulties that we shall encounter, however, is in the fact that in the open air we are not dealing with a limited confined space, but we have to do with unlimited space and a well-nigh frictionless medium. The apparatus which he used has been sufficiently described already. The earlier investigation with the nephelescope was made without the use of a condensing syringe; and in this we are able to comprehend clearly just the action which took place, while in the later researches the results were quite complex. Mr. Espy first carried his jar into air the temperature of which was quite low, at freezing or below; and, after it had attained the temperature of its surroundings, the stop-cock was closed, and the jar was taken to a room with high temperature, 70° to 80°. The air inside was expanded by the heat, and the amount of this expansion was measured on the gauge. He then opened the

stop cock, and closed it at the moment the mercury reached a level in the gauge. The rising of the mercury in the gauge after explosion, he thought was due to the gradual heating of the air which had been cooled by the sudden expansion. In the same way the jar was left in a high temperature for a time; then the stop-cock was closed, and it was carried to a low temperature. In this case, of course, the mercury in the gauge had the opposite motion to that it had before. The same experiments were tried with both moist and dry air.

One of the more important results from these researches, Espy does not seem to have thought of, though it dimly foreshadowed the epoch-making experiments of Mayer and Joule, in England, on the mechanical equivalent of heat. It is plain that in this confined space used by Espy there must be a relation between the amount of rise or fall in temperature and the corresponding change in air-pressure under a constant volume, and this will enable us to determine the expansion of air per degree of heat applied. In moist air the average difference of temperature between the cold and warm room was 45°, and the rise of the gauge 2.97 inches; in moist air, going from a warm to a cold room, the fall in temperature was 45°, and the fall in the gauge 2.60 inches: while with dry air these quantities were 57° and 3.34 inches and 63° and 3.30 inches respectively. The amount of change per degree in the four cases was .066, .057, .059, and .052 of an inch, or a mean of .059 of an inch in all the cases. The reading of the barometer is not given; but, if we assume it to be 29.80 inches, we find that the increase of temperature required to double the pressure in the jar was not far from 505°,—a result which is remarkably close to the 490° found by the more careful and extended researches of others. We now see the important bearing of this first work on our studies. If we compress air 5 inches by the gauge, we would heat it 83°; and if 10 inches, 167°; and so on, provided no heat was lost or dissipated in the operation. We ought also to be able to calculate from the reading of the gauge, after any operation of either condensation or expansion, exactly how much the air was heated or cooled, provided always that no heat was lost or gained.

In the light of this interpretation, let us examine some of Espy's experiments. In one instance he compressed the air 10 inches. We may suppose that he waited long enough to allow the jar to attain the air temperature before explosion. After the explosion the gauge reading was 2.15 inches, which would indicate that the cooling was not far from 36°, provided the only influence on the gauge was through the rise of pressure consequent upon the heating of the air by surroundings. It would appear that the theoretical cooling from such an expansion should be much greater than this; and, in fact, we cannot reason or theorize upon this result in any way, without first learning the probable loss of heat during compression, and its gain during expansion, to and from the environment. Espy's nephelescope was duplicated in its different parts, with the addition of a most delicate thermometer loaned by Professor Russell. This instrument has a bulb .06 of an inch in diameter and 1 inch in length, and would change one degree in from two to three seconds. It is plain, that, in observations with any degree of speed in *change* of temperature, any instrument will be liable to lag behind the existing temperature. This difficulty, how-